AGRICULTURAL ENGINEERING RESEARCH AND THE ENGINEERING EXPERIMENT STATIONS*

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Agricultural engineering consists of the application of civil, mechanical, electrical, and chemical engineering principles, and certain physical and physico-chemical phenomena to agricultural operations and practices. Its purpose is to introduce efficiency and economy into the agricultural industry.

The requirements of the agricultural industry for engineering have been found to be peculiar and exacting in many instances and often to differ somewhat from those of other industries, especially in that the matters for manipulation are largely of a biological character and individual units of the agricultural industry are usually relatively small as compared to those of other industries. Thus many inadequacies in the knowledge available from the older branches of engineering from the standpoint of the industrial requirements of agriculture have come to light during the past quarter century.

Naturally there was an early tendency to resort to investigation and research to remedy the situation. This tendency has grown steadily until there exists today in 40 of the land-grant research institutions an extensive program of research in the application of engineering and engineering physics to agricultural practices.

This program of research now numbers considerably more than 300 major projects of research and investigation, and employs in the neighborhood of the equivalent of 75 full-time research agricultural engineers, who are trained basically in engineering and physics and are generally versed in the industrial requirements of agriculture and in agricultural technology. It represented an investment during the fiscal year 1929-30 of approximately $350,000. The subject of power development and transmission and mechanical equipment leads with 132 projects at 33 different State research institutions. Structures is second with 41 projects at 21 institutions. There are 33 projects in irrigation at 13 institutions, 24 projects in drainage at 12 institutions, 32 projects in rural electrification at 18 institutions, 21 projects in materials of construction at 12 institutions, 13 projects in rural sanitary engineering at 9 institutions, 11 projects in land clearing at 6 institutions, and 10 projects in soil erosion at 9 institutions.

With a few outstanding exceptions the research in agricultural engineering has been conducted primarily in agricultural experiment stations, where the research equipment available was naturally not in general adapted to engineering

*Presented before the Engineering Section of the meeting of the Association of Land-Grant Colleges and Universities, November, 1930, at Washington, D. C.

research. It has been necessary in most cases to develop the research equipment from the ground up and to build almost entirely new research laboratories in some instances, and for obvious reasons it has been difficult to obtain support for engineering research facilities in agricultural research institutions. Thus the development of this research program has been slow under these handicaps.

However, agricultural engineering now is becoming rather well understood as a research subject by agricultural experiment stations. They are adopting an attitude of sympathetic encouragement which is resulting, in some instances, in the provision of more adequate/research facilities and personnel. They are also giving cooperation by supplying specific basic agricultural requirements which not only is making possible the extensive economic application of available engineering principles to agriculture, but in spite of limited facilities, virtually is forcing efforts toward the material modification of many of them. In some cases also it already has resulted in the development of entirely new principles of a distinctly agricultural engineering character.

It is recognized, however, that on account of the handicap of limited facilities for engineering research in most agricultural research institutions, this movement probably could still better attain its full objective with the cooperation of the engineering experiment stations, and in perhaps the majority of cases, with their active participation. This should take the form of the development and manipulation of engineering principles in the design of equipment and of the final practical testing of new equipment on a cooperative basis. An analysis of the existing research program in agricultural engineering suggests profitable lines of participation by engineering experiment stations which are particularly evident in the power and machinery field.

POWER AND MECHANICAL EQUIPMENT

The value of mechanical equipment on farms in the United States is reported to be in the neighborhood of $5,000,000,000. During the past 20 years this value has increased fourfold and the wealth produced per agricultural worker has shown a parallel and proportionate increase. Yet it has been ascertained from various sources that the total amount of primary power used on farms in the United States in 1928 approximated 18,100,000,000 horsepower hours, and cost in the neighborhood of $3,500,000,000. These figures are interesting when it is considered that power and labor costs are generally approximated at 60 per cent of the total cost of agricultural production.

It is also true that the fundamental principles of design of the steel moldboard plow, for example, which came into use about 1840 and which has always been a major power consumer, are still largely unknown. This condition also exists with other power-consuming farm machines to a greater or lesser degree.

Thus while economy and increased efficiency per worker have resulted in general through the mechanization of agriculture, it is in the important specific details of mechanical equipment such as that for plowing and cultivating, for example, where engineering research is needed to introduce further permanent cost-saving developments.

Tillage Machinery.--Tillage which includes plowing, harrowing, and pulverizing of soil in seed bed preparation, and cultivation of the growing crops has been found to require the expenditure of a tremendous amount of power, in some cases amounting to from one-half to two-thirds of the total power required for the production of a crop. Efforts to reduce this power consumption by better management have already been attended with considerable general saving in total production costs. However, the direction of attention toward some of the individual details of tillage have resulted in some permanent savings of a specific character.

The agronomists have been able to indicate the tilth requirements for different crops in various soils up to a certain point. The agricultural engineers have been translating these tilth requirements into terms of soil technology and thence into terms of the engineering properties of soil known as soil dynamics. The fundamental principles of soil dynamics now are becoming known and data on their application to a limited number of soils are available. With this knowledge it is rapidly becoming possible to design a plow moldboard or other tillage tool with reference to shape, size, strength, sharpness, and metallurigical characteristics which will produce a given required degree of tilth in these soils with a minimum power expenditure for such specific factors of draft, as, for example, friction between the soil and the metal surface, shearing, pulverization, and the like. Outstanding work of this character is in progress at the Alabama Agricultural Experiment Station and a few other stations have made beginnings.

These researches are proceeding along definite cost-saving lines and already have accomplished a lot. However, there is yet a tremendous amount to be done on the factors of plow draft before tillage operations are brought to a maximum of efficiency and economy. The necessity for extensive and profound researches in engineering physics, mechanics, and metallurgy in connection with such studies of soil dynamics, and their relation to tillage implement design, places quite definite limitations on this work in the agricultural experiment stations on account of the research equipment required. This very necessity, however, would seem to place these features of the study in the field of the engineering experiment station and to offer an opportunity for a definite worth while undertaking in agricultural engineering in cooperation with agronomy and soil technology of the agricultural experiment station.

Draft Machinery.--Field crop specialists are laying down the requirements for tillage and harvesting operations, and power propelled and operated machines are being developed to perform these operations. The tractor was developed origanially to supply the draft and other power for each operation, but owing to the peculiar and sometimes very severe conditions of service encountered in agriculture, it was often not efficiently or economically adaptable. It was necessary, therefore, to undertake the redevelopment of tractors along certain specific lines. The tractor is now considered as a complex of several problems each requiring a definite and limited study. Special attention is being devoted to the redevelopment of such specific features as traction, stability, steering, bearing wear and lubrication, carburetion, intake air cleaning, and the like to meet certain of the severe requirements imposed by individual agricultural operations.

In the study of traction, for example, the object of researches at the Alabama, California, Iowa, and a few other agricultural experiment stations is to elucidate the principles of design of tractor wheels which will give maximum tractive impluses under given conditions of soil, engine power, tractor weight, and weight distribution. This involves a consideration of the distribution and concentration of tractive impulse stresses in soil from drivewheel rims and lugs in their relation to the dynamics and kinematics of the tractor as a whole.

The limitations of such research work in the agricultural experiment stations generally are in facilities for the necessary studies in engineering physics, mechanics, kinematics, and metallurgy. Here again is a definite opportunity for the engineering experiment station to cooperate with the technologists of the agricultural experiment station in a very specific problem of tremendous economic importance.

The investigations in the field of fuel technology also have shown that different conditions of carburetion, fuel composition, and gaseous explosion are required for the optimum performance of tractors under various severe conditions of agricultural service. Such work is limited in the agricultural experiment stations by the lack of chemical engineering research facilities. Since agriculture utilizes so much power and so large a proportion of it is now mechanical in character it would seem worth while for the engineering experiment stations to devote sometime to tractor fuel problems as they relate to the requirements of specific types of agricultural performance in both draft and power takeoff operations. A more thorough knowledge of liquid fuels may possibly lead to greater economy in power utilization which will be reflected particularly in more satisfactory and flexible performance of traction machinery.

The situation is similar with reference to bearing wear and lubrication, intake air cleaning, steering and other tractor features, all of which must be developed to meet specific, peculiar, unusual and generally very severe agricultural requirements and involve definite cost-saving considerations. In every such instance a few agricultural experiment stations are making progress in spite of lack of facilities. However, the fields of activity of the engineering experiment stations seem clear in each case the the features of cooperation with the agricultural experiment stations are easily understood.

Harvesting and Threshing Machinery.--Much has been accomplished in recent years along cost-saving lines by the practical combination of the harvesting and threshing operations. It is now becoming possible to handle small grains, grain sorghums, beans, and even corn by this process at a considerable saving of time and labor. However, it is known that at this stage power and grain are being wasted by the use of methods and equipment which are inefficient in some of their details so that the maximum of efficiency in the combining process has not been attained.

Efforts now are being made by the agricultural experiment stations to determine what actually takes place when grain is properly cut, threshed, and artificially dried, what are the basic mechanical and thermodynamic requirements therefor, and to what extent and in what specific respects available equipment falls short of adequately performing these operations. The redesign and practical testing of deficient features is also an important feature of this work on which considerable progress has been made.

This work is usually limited in the agricultural experiment stations by the lack of facilities to carry these investigations through the necessary studies of physics, mechanics, kinematics, and thermodynamics necessary to develop the principles of design of the important details of cutting, binding, threshing, elevating, and drying mechanism to the point of maximum efficiency. Herein the engineering experiment stations are offered an opportunity to function in an extensive and profitable manner in cooperation with the agricultural experiment stations.

Similar conditions exist with reference to the development of potato-harvesting methods and equipment. The investigations in this line at the Pennsylvania Agricultural Experiment Station, for example, have been centered on such power and labor-consuming details as digging, cleaning, elevating, and the like, they being the greatest consumers of labor and power under a heavy crop. Lubrication of these machines, for example, offers quite a problem, as the depreciation in the oscillating and reciprocating parts of cleaning and elevating devices operating under most severeconditions of abrasive dust, sand, and soil, is very high. Here indeed are problems of machine development and design involving profound studies in engineering physics, metallurgy and lubrication to meet the extremely severe conditions of an important agricultural operation which will test the mettle of any engineering experiment station.

In substance the field of farm power and mechanical equipment appears to offer numerous definite opportunities for research and investigation in agricultural engineering in cooperation with agricultural experiment stations which seem to be not only eminently worthy of the consideration of engineering experiment stations from the economic standpoint but to fall clearly within the scope of their legitimate operations.

STRUCTURES

It has been estimated that the present farm building construction in the United States represents an investment of approximately $11,750,000,000. Estimating depreciation and taxes conservatively at 6 per cent, it requires an annual outlay of over $700,000,000 to maintain the structures represented by this investment.

The structures most prominently concerned in these figures are farm dwellings, poultry and livestock shelters, dairy buildings, and crop and commodity storages. While the amount of money involved in farm structures throughout the country is large, the investment in the individual structure is usually relatively small, ranging anywhere from $500 to in the neighborhood of $5,000.

In spite of the vast total investment in farm structures they have been built largely without the aid of engineering and have been found to be inadequate in many respects. Agricultural experiment stations are attempting to establish the specific agricultural requirements as well as the economic limitations for farm buildings, but frequently the principles available from the older branches of engineering are not adapted to their rational design largely because of the size and necessary arrangement of the individual units and their peculiar requirements for service.

Due largely to the lack of research facilities the program of research in farm structures so far has been comparatively limited in scope in the agricultural experiment stations when the investment in farm structures is considered. However, if the 13 projects in farm home sanitation and the 21 projects in materials of construction are included, the program at the agricultural experiment stations reaches a total of 75 active projects at 28 stations.

Animal Shelters.--From the strictly agricultural standpoint animal shelters and poultry and dairy buildings perhaps offer the most important structural problems. It has been found, for example, that housing conditions which control temperature, air movement and supply, and humidity are important factors in the profitableness of the animal, dairy and poultry industries. Dairy stock of different breeds, for example, are now known to present individual requirements for ventilation, temperature and humidity for maximum quality production. One agricultural experiment station has indicated a relation between milk quality and temperatures inside and outside of the dairy barn. In poultry housing the control of temperature and rates of air movement to secure uniformity of environment also has been found to be of primary importance in securing maximum quality production.

Valuable work already has been done by a few of the agricultural experiment stations in determining the specific housing requirements of different animals and in the general development of ventilation and heating methods and equipment. However, the limiting factor in this type of research in the agricultural experiment stations is probably the difficulty of securing and utilizing an adequate control technique in which all important housing factors can be isolated and varied at will. The development of this technique and the corresponding research equipment is of vital importance to the success of the work, but has rarely been attained. An outstanding instance is that used in studies of the air requirement of poultry at the Iowa Agricultural Experiment Station. The development of such technique involving studies of materials, heating and ventilation equipment, temperature, humidity, and the physics of air movement under the different conditions imposed to provide the air movement, temperature, and humidity required for specific cases would appear to offer a promising opportunity for the engineering experiment stations to participate in farm structures research in cooperation with the agricultural experiment stations.

In addition, all such animal shelters must be structurally sound and durable and fully practical from the standpoint of engineering design and construction. It is known, however, that some of the better types of barn roof truss construction, for example, are statically indeterminate or practically so, thus reducing the engineering design of such structures to a matter largely of speculation. Thus the design of important members and joints often may be based mainly on tradition rather than on engineering facts and principles.

The necessity for durability and fireproofness, in addition to ultimate economy in space arrangement as well as in construction is bringing about the development of animal shelters and general purpose barns of reinforced concrete, tile, sheet steel, and the like. Efforts also are being made at the Iowa Agricultural Experiment Station, for example, to develop reinforced concrete and tile arch roofs to meet the space and other interior arrangement requirements of certain barn types most economically.

Here again it would appear that the limitations on this important line of research in the agricultural experiment stations are research facilities and equipment. The specific requirements for economical and efficient animal shelters can be established by the agricultural experiment stations, but it would appear to be a logical function of the engineering experiment station to develop and manipulate the principles of engineering mechanics and structural design which will meet these requirements in the most satisfactory manner.

Crop and Commodity Storages.--The agricultural experiment stations have established the fact that, physiologically, crops vary quite widely in their storage requirements. The factor of storage diseases complicates the situation and it also is being found that type of storage may profoundly influence the nutritive quality of certain stored crops. In addition small grain and corn crops are likely to spoil if stored in a green condition. In the past the practice often has been to build a storage structure by rule of thumb and to expect and passively accept a percentage of loss or decreased value.

The tendency now is, however, to study the storage requirements of individual crops such as potatoes, sweet potatoes, apples, beets, carrots, green grain, soft corn, and the like, from the physiological, pathological, and biochemical standpoints, in order to arrive at something definite in the way of specifications which can be used as a basis for the development of the types of storage structures necessary to prevent these losses. Here again the necessity frequently arises for controlled studies of the physics of air movement and temperature and humidity control, combined with a manipulation of structural mechanics and of the properties of materials of construction to specifically meet the storage requirements of individual crops. Here again these features of the general problem appear to lie in the field of the engineering experiment station and offer opportunities for constructive research in cooperation with the agricultural experiment station along definite profit-increasing lines.

In substance the new, unusual, and interesting field of research in farm structures would seem to offer the engineering experiment stations numerous definite and worth while opportunities for both specific investigations and original inquiries in physics, structural mechanics, thermodynamics, and materials of construction in cooperation with the animal production and field and horticultural crop specialists of the agricultural experiment stations through the medium of the agricultural engineer.

ELECTRICITY IN AGRICULTURE

The 1929 report of the Director of the National Committee on the Relation of Electricity to Agriculture states that there are substantial reasons for believing that the number of farms in the United States having electric service is well above the 800,000 mark and that over 500,000 of these have so-called high line service. While data are not available to show the annual growth of rural electrification in the entire United States, it is interesting to note that in Alabama the mileage of rural lines owned by one power company increased from 39 in 1924 to 1,495 in 1930, and the number of rural customers from 240 to 8,609 for the same period. That company reported in January, 1930, that the energy

consumption by rural customers varies from 600 K.W.H. per year per customer on lines less than one year old to 993 K.W.H. per customer per year on lines five years old and older with an average consumption of 840 K.W.H.

Similar data from other States indicate that the extensive agricultural use of electricity is now an established fact and that this practice is growing by leaps and bounds. Agriculture has learned something of the convenience and flexibility of this source of energy and is demanding that its application be extended sufficiently to make its use generally profitable.

The investigational work in rural electrification has been rather limited in public research institutions largely for the reason that up until recently a considerable proportion of that active was financed and conducted by private agencies. Another reason was that when the movement started there was a wealth of electrical engineering information available to the agricultural engineer, which was susceptible of immediate practical application to agricultural practices, and the problems encountered were largely of a practical rather than a fundamental character.

It is now being recognized, however, that the initial supply of practical engineering information, while relatively large, is not sufficient to bring about general rural electrification. The necessity of ultimately developing enough additional uses of electricity in agriculture to make rural electrification fully worth while for all concerned is evident on account of the growing demand.

In this connection a study of the programs of agricultural research at the agricultural experiment stations revealed a large number of instances in which electricity is or may be made to play an important part in the development of important agricultural practices.

Each instance of this character, on analysis, has been found to call for individual fundamental study in cooperation with the agricultural specialists concerned in order to develop the use of electricity along sound and permanent lines. Crop and dairy products processing, disease and insect control, animal nutrition, crop stimulation, poultry production, and even field draft operations offer opportunities for the profitable building up of the rural electrical load. Each instance calls for research in physics and electrical engineering, which for obvious reasons falls within the field of the engineering experiment station.

RECLAMATION

For convenience reclamation as a branch of agricultural engineering has been considered to include farm drainage and irrigation, land clearing, and soil erosion and runoff prevention.

Drainage and Irrigation.--The irrigation and drainage features of reclamation are not new to engineering experiment stations, having for a long time been considered as falling exclusively within the field of the civil engineer.

However, since irrigation and drainage have been taken up by the agricultural experiment stations as branches of agricultural engineering, research in them has taken on a somewhat new aspect. The drainage investigations have been narrowed down from the broad general demonstration type of field drainage experiment to studies of the principles of soil hydraulics governing the movement of water through different soils under the influence of drainage equipment installations. The purpose is to provide a sound technological basis for the engineering design of drainage systems to meet the specific requirements of different crops, soils, and climates.

Similarly the irrigation studies are aimed at the establishment of the principles governing economical and efficient irrigation practices. They are undertaking to secure information relating to the basic requirements of different crop plants for water and are attempting also to elucidate the principles governing the existence, movements, and factors of availability of water to crops in various soils and how these may be controlled by the application of hydraulic engineering principles in the form of water application practices and equipment.

Thus a field of research in the hydraulics of drainage and irrigation is offered the engineering experiment station, which extends considerably beyond a consideration of the flow of water in tile, pipe lines, flumes, ditches and canals. It calls for cooperation with plant physiology and soil technology of the agricultural experiment station and for the manipulation of physics and engineering hydraulics by the engineering experiment station. It is aimed ultimately at the provision of basically sound principles for the rational and economical design of drainage and irrigation practices and equipment.

<u>Soil Erosion and Storm Runoff Prevention.</u>--The U.S. Department of Agriculture has estimated that not less than 126,000,000,000 pounds of plant food material is removed from the fields and pastures of the United States every year by erosion under the influence of storm runoff at a cost of $200,000,000. This does not consider the additional loss of water involved.

Research in this important field now calls for cooperation between engineers, soil technologists, and field crop specialists in studies of the basic factors in the erosion of different soils and how they may be controlled by artificial means or by the manipulation of natural processes. The necessity of conducting these studies under controlled conditions is reflected in the fact that some of the agricultural experiment stations, notably those in Alabama and Texas, are attempting not only to control field plats but also to carry feature of the work into the laboratory in order to isolate both agronomic facts and soil engineering principles responsible for erosion and storm runoff losses. It is thus evident that there are numerous opportunities for profitable participation by the engineering experiment stations in those features of the work relating to the manipulation of physical and hydraulic engineering principles both in the laboratory studies and in the final design and construction of field prevention measures.

Land Clearing.--Land clearing is an important branch of land reclamation in which it appears that the engineering experiment stations have a definite function to perform. The problem at present seems to be to adapt the many different available clearing methods and equipment to different local conditions with the least cost. Much general data are now available on the lifting and shattering power of different explosives and on the relative efficiencies of different mechanical clearing devices in terms of the resistance of stumps, stones, and the like, to shattering and removal.

However, stone, stump, and brush removal are at best very costly practices and there is yet considerable to be done of a purely engineering character toward further improvement in some of the details of the available mechanical and chemical methods and equipment along definite cost-saving lines.

CONCLUSION

The above brief analysis of agricultural engineering research at the land-grant research institutions indicates some of the outstanding opportunities for participation by engineering experiment stations in a profitable field of research. Since 1820 when 87 per cent of the approximately 7,000,000 total population of the United States were gainfully occupied in agriculture the processes of agriculture have been developed through improved equipment and methods and the introduction of mechanized practices until at present a population of in the neighborhood of 120,000,000 people is fed by barely 25 per cent of their number. The efficiency of the agricultural worker has been increased many fold, especially during the past half century.

However, the striking fact that practically a fourfold increase has occurred in the wealth produced per agricultural worker during the past 20 years since agricultural engineering has been recognized as a distinct branch of engineering would seem to indicate that the agricultural engineer, the man trained basically in some branch of engineering and sufficiently trained in agriculture to fully and intelligently recognize its basic industrial requirements, is the most important single factor in agricultural engineering research. A personnel well trained in agricultural engineering, as such, is essential to the success of research in the subject.

There are already in existence several hundred projects of research and investigation in agricultural engineering at the land-grant research institutions. In a considerable number of these projects the distinctly engineering features have been organized by agricultural engineers and are ready to go, but appear to be prevented from making the desirable rapid progress largely on account of the naturally limited facilities for physical and engineering research available in the average agricultural experiment station. In such cases it would seem that about all that is needed is action by the engineering experiment stations.

In substance, it seems safe to say that a well rounded program of research on the distinctly engineering features of the application of physical and engineering principles to the practices of the industry of agriculture is available and ready to be put into effect in large part on short notice, and that the nucleus of an agricultural engineering research personnel is available to get it under way.